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Live finger

This invention relates to a sensor assembly and method for determining the condition of a structure, especially for confirming if a measured fingerprint is on a live finger, by measuring characteristics of close to the structure surface.

5 Introduction

Capacitance or impedance based fingerprint sensors are some of the most promising approaches to offer a low-cost, miniaturized device for biometric identification. Such sensors are therefore possible candidates for integration in mobile phones etc.

10 To enhance the trust of fingerprint sensors, it is of great importance that any attempt to fool the system by using fake fingers may be detected and rejected. A fake finger will typically consist of a slab of material with electrical properties resembling that of a finger, and with a fingerprint carved or molded into its surface. In a more extreme case one may also imagine that a dead, cut-off finger may be used.

15 For live finger detection systems, it is important both that the probability of accepting a false finger (false acceptance ratio - FAR) and the probability of rejecting a real finger (false rejection ratio - FRR) are extremely low. This makes it important to develop a method for identifying very characteristic and unique properties of a living finger, properties that can not easily be replicated by either synthetic materials or by
20 other biological substance than living tissue, and which are typical of the vast majority of fingers in the population.

For low cost capacitive based fingerprint sensors some kind of impedance measurement of the finger properties will be ideal, as it can most often be integrated directly on the device by using existing measurement structures or adding a number of
25 extra electrodes.

Prior art

Several different types of fingerprint sensors have recently been developed, from 2-dimensional matrix sensors as described in US 5,953,441 through
30 sensor arrays reconstructing the fingerprint image from series of semi-overlapping partial images in US 6,289,114 to linear sensors as described in PCT/NO98/00182 which scans the finger surface and uses the measured finger velocity to reconstruct the finger image.

Attempts to detect live fingers include both blood oxygenation and blood pulse measurements. However, as the blood circulation in the finger may be virtually non-present in very cold fingers, these methods are far from being "water-proof". Neither are these principles easy to implement on a low cost device.

5 US Patents 6,175,641, 5,953,441 and patent application US2001/0005424 A1 all show different impedance based methods of investigating whether an object which is placed on a fingerprint sensor corresponds to a live finger.

US patent 6,175,641, which relates to impedance sensing on an optical matrix sensor, shows two different methods for measuring the electrical characteristics of the finger: Firstly, the dielectric constant is measured locally by applying an AC
10 signal between two closely spaced electrode comb structures on the sensor surface. It is claimed that this measurement can separate living tissue (high dielectric constant) from commercial plastics (low dielectric constant).

Secondly, the sensor has a so-called double dot electrode for determining
15 the impedance of the finger, which presumably will give additional information that can be used to distinguish real fingers from fake. The patent also mentions the use of several frequencies to increase the security of the measurement.

The method described in this patent however has a number of weaknesses. While the dielectric measurement will perhaps work well for dry fingers, for sweat or
20 humid fingers the closely spaced comb structures will most probably be shortcircuited by saline sweat, and no useful information will be obtained.

In addition the impedance of a living finger, as measured by the double dot system, may vary with at least one order of magnitude depending on the humidity of the finger. It is therefore difficult to use this as a criteria to identify a finger, and both
25 the impedance magnitude, its phase and its variation with frequency could probably be faked by simple well-known materials from everyday life, such as a peeled potato.

Patent 5,953,441 describes spoof detection for an AC capacitive fingerprint sensor containing a matrix of capacitive sensing elements. The main idea for live finger detection is here to send AC signal through an electrode around the rim of
30 the sensor area, and to detect the phase of the signals on the sensor elements, this phase being characteristic of a living finger.

However, while this method will rule out a number of different fake finger materials, it will be relatively easy to find a material that gives approximately the same phase as a finger, and thereby to fool the system.

Patent application US2001/0005424 A1 shows a method resembling the method described in 6,175,641. The impedance of the finger (either between two electrodes or between one electrode and "infinity") is measured as a function of frequency. By comparing the curve to a reference curve the living characteristics of a finger may then be detected. This method however adds little to the methods described above. The absolute impedance and frequency response between different fingers, and between different states (e.g with respect to humidity) of the same finger, differ so much that the "live finger criteria" would have to be very wide, and so the principle would be easy to fool.

Norwegian patent application 2002 2310, hereby included here by way of reference, shows another live finger detection principle, based on four point measurements of complex impedance. Here, an AC current or voltage is applied between two electrodes while measuring the voltage drop between two other electrodes, all electrodes being in contact with the finger surface. The four-point principle, applied to finger impedance measurements, is visualized in figure 1. An AC current is sent through the finger through the outer electrodes, while the voltage drop is measured between the two inner electrodes using a differential amplifier and the impedance may be calculated based on the known current.

The use of a four point technique makes it possible to cancel out the series impedance of the horny layer, thus directly measuring the impedance of the finger interior. The impedance of the horny layer is extremely dependent on the humidity of the skin and on ambient conditions such as temperature. This makes it difficult to identify "narrow" criteria that may be used to separate real fingers from fake. In contrast, the humidity of finger interior remains fairly constant under varying ambient conditions. The impedance of the finger interior (living skin and tissue) is therefore far more constant, and more reproducible from person to person.

The four-point principle will thus make it easier to obtain "narrow" criteria that can be used for identifying whether a finger is a real and live finger.

Because of the layered structure of the skin, the four point principle also gives an inherent "depth selectivity": By increasing the frequency the measurement is influenced by still deeper portions of the living skin. This makes it possible to measure depth-specific variations in the electrical properties merely by carrying out a frequency sweep.

The living tissue of the finger interior also has very characteristic dispersions (variation in electrical properties with frequency) that can be used to identify a real finger with a high degree of security. These properties change after death or when a finger is cut off from the hand, and makes it possible also to determine whether the finger is live.

One weakness of the principle proposed in 2002 2310 is that the four-point impedance is that the impedance is measured with only one set of electrodes where all electrodes have a fixed distance.

Depending on the relative positions of the electrodes of the four-point structure, the impedance measurements will however be more or less affected by the stratum corneum (horny layer).

In the limit of a very short distance between the current electrodes, the current will not penetrate into the living skin of the finger interior at all, thus giving a measurement only of the stratum corneum alone.

In the other limit, with a large electrode distance, the measurement will be largely determined by the properties of the living tissue of the finger interior.

Because different people have different stratum corneum thicknesses, a fixed electrode distance will give different results for different people, thus making it difficult to identify a living finger without using very wide criteria. If the criteria are not narrow enough, the principle will be easier to spoof.

Summary of invention

The aim of the current invention is to ensure a four-point measuring system for live finger detection that can be used to compensate for differences in finger characteristics among a population, such as a varying stratum corneum thickness.

To reach this aim, the proposed invention consists of an impedance measuring system with an array of at least four electrodes. The electrodes may be in

direct contact with or capacitively coupled to the finger through an insulating layer. The electrodes are arranged in such a way that they can be used in at least two different four-point electrode configurations, corresponding to different relative placements between the current and voltage sensing electrodes. The objects of this invention is obtained as
5 described in the accompanying claims.

It will be known to the skilled engineer that different electrode configurations, where the electrodes have different relative placements, corresponds to the measurement of different portions of the object adjacent the electrodes. The portion of a finger that is measured by the four-point principle is however not only determined
10 by the distance between the two current sensing electrodes and between the two voltage sensing electrodes, but also on the electrode geometry and the relative placement of the voltage sensing electrodes with respect to the current electrodes.

By activating different electrodes in the array or by interchanging the role (voltage sensing or current) of electrodes already in use, it can therefore be switched
15 between different four point electrode configurations.

By switching between a number of different electrode configurations within the array it will thus be possible to measure sections of the finger e.g corresponding to different measuring depths, and thus compensate for variations in e.g stratum corneum thickness.

20 To exemplify, a characteristic dispersion (shift in complex impedance with frequency) that is observed for one person using one electrode arrangement, may be detected for another person using another arrangement.

To reveal the same dispersion, a person with a very thick stratum corneum may for instance require a larger distance between the current injection or voltage
25 sensing electrodes than a person with a thin stratum corneum.

A minimum criterion for accepting an object as a live finger may be that at least one specific, impedance related phenomenon is detected for at least one of the electrode arrangements.

It should be emphasized that the focus on "differences in stratum corneum
30 thickness" is only exemplary. The principle applies to all properties of the finger where a shift in electrode geometry may help to reveal certain impedance related phenomena within a given frequency range.

Preferably, to enhance the security of detecting a live finger across a significant population, the number of possible electrode configurations may be higher than two, for instance 3-5. The various configurations can of course be arranged in the form of separate arrays so that a minimum of switching is required.

The invention will be described below with reference to the accompanying drawings, illustrating the invention by way of example.

Figure 1 illustrates the electrical equivalent of a two layer structure being interrogated by a sensor assembly according to the invention.

Figure 2 illustrates one possible configuration for switching the roles of a number of electrodes according to the invention.

Figure 3 Multivariate model of to distinguish between live fingers and other objects. Note that if only one of the variables (either variable 1 or variable 2) are used, some of the "false fingers" (marked with red) are likely to be mistaken for real fingers.

Practical implementation

In figure 1 a finger surface 11 is positioned on a number of sensors 10. The finger structure comprises two layers, the stratum corneum 12 and the live tissue 13 of the living finger. The stratum corneum (horny layer) 12 constitutes impedances Z1, Z2, Z3 and Z4, respectively, at each of the four electrodes 10, while the living tissue represents the impedance Z0.

In a practical device, a four-point measurement may be implemented by an array of electrodes 10 on the sensor surface, e.g. defined in thin film, thick film or printed circuit board technology. The electrodes 10 may either give a galvanic contact with the finger or be passivated with a thin dielectric to give a pure capacitive coupling from electrode to finger.

A typical size of the individual electrodes (both current and voltage electrodes) will be $0.5 - 5 \text{ mm}^2$, and a typical minimum electrode spacing will be $0.3 - 2 \text{ mm}$.

Figure 2 shows an example of how an array of 8 electrodes can be arranged to allow for measurements at a number of different current electrode distances.

In this structure, the voltage measurements are always performed between the electrodes 4 and 5, while the two switches S1 and S2 are used to make different combinations of the electrodes 1,2,3 (AC source 15) with the electrodes 6,7 and 8 (AC drain or ground 14), and thereby vary the current electrode distance. Alternatively, the role of the current and voltage sensing electrodes can be interchanged so that current is always sent between the innermost electrodes and the voltage measurement is switched between various combinations of the remaining electrodes. If the role of the voltage sensing pair is interchanged with the current electrode pair, the measured impedance remains essentially the same.

By choosing the range of inter-electrode distances corresponding to stratum corneum thickness variations in the population (or other variations that give corresponding effects, such as differences in humidity), it will be possible to obtain information that can be compared more directly and thus used to "narrow" the criteria for a real finger. This will enable live finger identification with a higher degree of certainty than any of the above described methods.

In designing the read-out system, it is important to maximize the input impedance in the voltage sensing branches, as a too low impedance will give rise to a parasitic input current that influences on the measuring principle. To minimize the effect of input impedances, an amplification coupling as described in US 4,956,729 can be employed.

If the input impedance of the amplifier is sufficiently high, the detected voltage will not be influenced by the impedances Z2, Z3, Z1 and Z4 (figure 1) through the horny layer, but only by Z0, being characteristic of the finger interior.

It should be emphasized that the disclosed system in figure 2 is only one possible way the electrodes can be arranged. In principle, all electrode arrangements yielding two or more different electrode configurations can be used. For voltage sensing, the fingerprint sensor elements themselves can be used.

Upon live finger detection, four-point complex impedance measurements are obtained for each of the electrode arrangements for a single frequency or across a range of frequencies. By measuring the amplitude of the current through the finger and the differential voltage in at least two different time instants during a signal cycle, the reactance X0 and resistance R0 of the complex impedance $Z0 = R0 + jX0$ can be

determined for each frequency. Other techniques for detecting the components of the complex impedance may also be used.

Live finger data will preferably be recorded right before, right after, or most preferably, during the course of fingerprint image capturing. This makes it difficult to spoof the system by first applying a real finger and then a fake finger with the correct fingerprint pattern. In some systems, the live finger detection and fingerprint imaging may not be done at the same time due to conflicting signals. In this case, it is possible to suspend the fingerprint imaging for short time intervals and carry out the live finger detection within this time frame. It is then important that the time for live finger detection is short enough to avoid affecting image quality significantly.

For a sweep sensor of the type described in PCT /NO98/00182 this could be accomplished by skipping e.g. one or two lines of image data and perform the live finger detection during this time. As mentioned above this solution comprises a number of sensor elements for measuring the impedance between a stimulation electrode and the sensor elements. According to the present invention the role of the sensor elements may be altered for one or a few measuring periods for measuring the condition of the finger. As the solution described in the abovementioned application allows for over sampling and rejection of unnecessary data the live finger detection mode should not be noticeable in the resulting fingerprint image.

It is also important that the geometrical area used for live finger detection overlaps the area used for fingerprint imaging, so that one can be certain that the detected live finger and the imaged objects are indeed the same.

As previously described, the criterion for accepting an object as a live finger may be based on measurements of at least one impedance related parameter from at least one of the electrode configurations.

This parameter may e.g. be a value or combination of values related to the measured impedance, such as the phase, magnitude, resistance or reactance, or it may be a variation of some value with respect to frequency. The parameter may also be some derived value, e.g. the frequency at which some parameter attains a certain value. The means for obtaining these measurements are per se known, and will not be described any further here.

Preferably, however, the criterion is based on the measurement of more than one parameter. A set of relevant parameters or variables can e.g be found by feeding obtained impedance data into a multivariate model.

5 Through statistical analysis of measured data from live and fake fingers such a model will output a set of weighted, combined variables (typically two or three) that are optimized for distinguishing real from fake fingers.

Preferably, the variables are normalized and statistically independent.

10 Which electrode configuration to be used for obtaining the desired variables will preferably be determined by the signal processing system based on measurements on several of the electrode configurations.

Alternatively, one configuration is measured at a time until the measurements match the given criterion.

Measurements obtained from different electrode configurations may also be combined.

15 Two-point impedance data or other measurements on the finger (e.g temperature) may be used in combination with the four-point data to enhance the selectivity towards fake or dead fingers.

Only objects where all the specified variables fall within certain limits will be deemed a live finger. Other objects will be rejected.

20 This is shown schematically in the figure 3 for a model with two variables V_1, V_2 , where only objects that fall within the indicated oval area LF (obtained data shown as triangles) are considered live. The circles outside the oval correspond to data for rejected objects RO.

25 In summary, the preferred method, which requires not only one specific value but a set of variables to be within certain limits, will make it extremely difficult to construct a "false finger" material. On its side, dead fingers will be rejected due to biological processes taking place in the finger after death, changing the electrical parameters.



P a t e n t k r a v

1. Sensor assembly for determining the condition of a structure, especially for confirming if a measured fingerprint is on a live finger, by measuring characteristics of close to the structure surface, the sensor comprising:

5 at least four electrodes with chosen positions relative to each other, of which a first pair constitutes current supply electrodes coupled to a current source, providing an electrical current to the skin, and a second pair constitutes two pickup electrodes, being coupled to an instrument for measuring the voltage between said pickup electrodes for obtaining a value characterising the structure,

10 storage means for storing a predetermined set of values characterising a certain condition of the structure,

and calculation means for comparing the characteristics from each pickup electrode with the measurements of the other pickup electrodes and with the predetermined set of characteristics for determining whether the structure is in the
15 certain condition.

2. Sensor assembly according to claim 1, comprising switching means for sequentially supplying current through any first pair of electrodes thus constituting the current supply electrodes and measuring the voltage through a second pair of electrodes
20 thus constituting the pickup electrodes.

3. Sensor assembly according to claim 1, wherein said instrument coupled to the the pickup electrodes measures the voltage between the pickup electrodes.

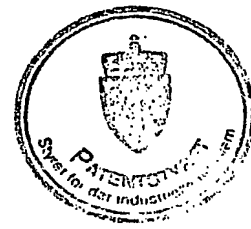
25 4. Sensor assembly according to claim 1, wherein the supplied current is oscillating within a chosen frequency range.

5. Sensor assembly according to claim 1, wherein the distance a first of said supply electrodes and sad first pickup electrode is less than 1mm.
30

6. Sensor assembly according to claim 1, wherein the electrodes are constituted by sensor elements in a fingerprint sensor array.

7. Method for characterising the condition of a structure close to its surface, e.g the electrical characteristics of two outer parts of the skin, i.e. the stratum corneum and the viable skin, using at least four electrodes coupled to the surface, comprising the steps of:

- applying a current to the skin between a first pair of current supply electrodes,
- measuring the voltage between a second pair of pickup electrodes,
- sequentially changing the roles of the electrodes so as to apply a current through a second pair of current supply electrodes and measuring the voltage between a second pair of pickup electrodes,
- comparing the measured impedances with a predetermined set of values characterising at least one condition of the structure,
- determining the condition of the structure based on the comparisons between the measured values and the predetermined set of values.



Abstract

Sensor assembly for determining the condition of a structure, especially for confirming if a measured fingerprint is on a live finger, by measuring characteristics of close to the structure surface, the sensor comprising:

at least four electrodes with chosen positions relative to each other, of which a first pair constitutes current supply electrodes coupled to a current source, providing an electrical current to the skin, and a second pair constitutes two pickup electrodes, being coupled to an instrument for measuring the voltage between said pickup electrodes for obtaining a value characterising the structure, storage means for storing a predetermined set of values characterising a certain condition of the structure, and calculation means for comparing the characteristics from each pickup electrode with the measurements of the other pickup electrodes and with the predetermined set of characteristics for determining whether the structure is in the certain condition.

Figure 1



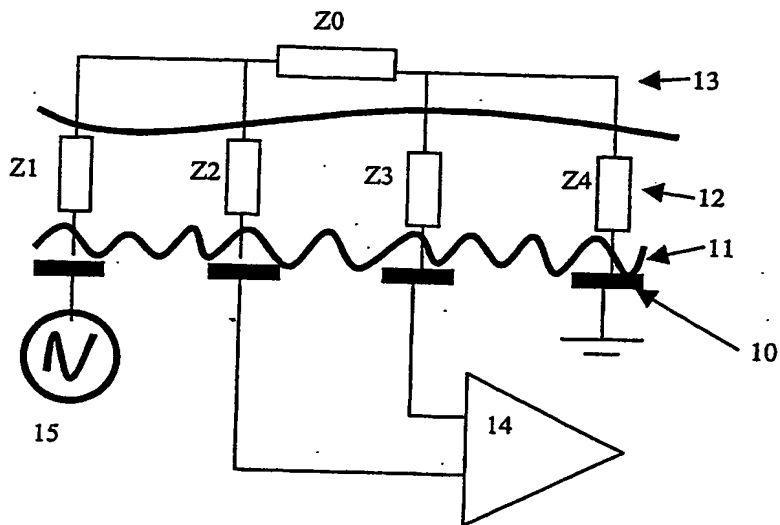


Figure 1

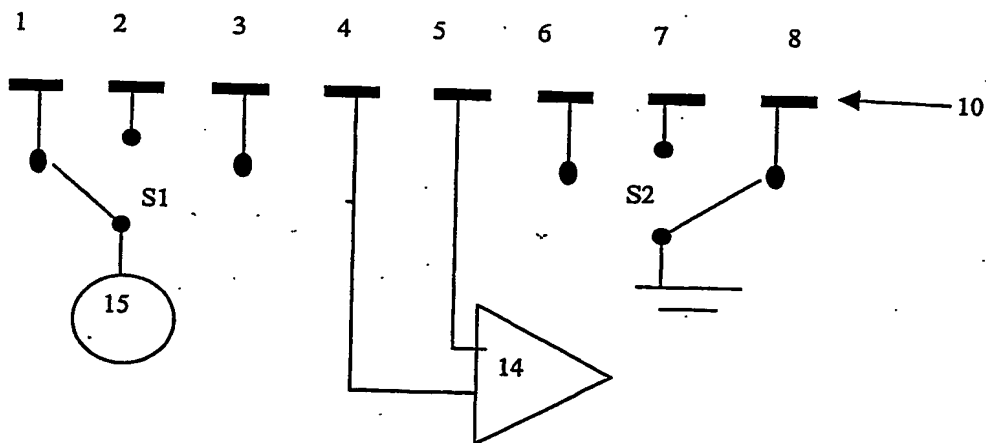


Figure 2



2/2

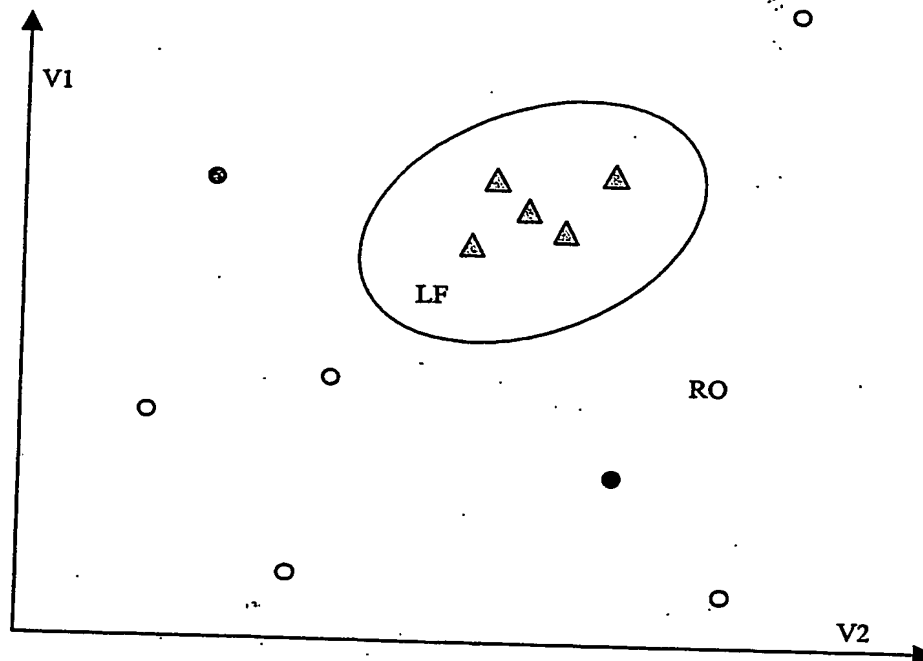


Figure 3

